ENVIRONMENTAL
Fact Sheet

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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Radon in New Hampshire

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INTRODUCTION

Radon is the 86th element in the chemical periodic table. Odorless, colorless and chemically inert, it is a naturally occurring radioactive noble gas that is found at varying levels everywhere in the environment.

Radon can only be sensed with instruments, specifically the Geiger counter and, indirectly, with a scintillometer (gamma sensor). Because the gas has a high density, it does not mix well with the Earth's atmosphere. Thus, it tends to be concentrated in low places in the natural environment, including valley floors or topographic depressions and in basements in the built environment.

Radon is appreciably soluble in water, inversely proportional to the water temperature. This relationship has important repercussions which allow, for example, radon to be easily degassed into the built environment from a combination of heating and aeration of the groundwater in the bathroom shower.

Radon is especially mobile in groundwater, moving in response to the gravity gradient within saturated fractured bedrock and surficial deposits. The gas is also mobile in air within the fracture network of the bedrock and the pore space of the surficial deposits. Here, it moves by a combination of flow and diffusion, and is sometimes called "soil gas" in levels near the surface of the earth. In some cases, radon in groundwater can be exchanged into the air in soil and fractured rock by evaporation. Radon-bearing air is also capable of migrating directly into an unsealed built environment, especially basements.

HEALTH RISK

The health risk from radon was not generally accepted until the 1960s when a statistical study of the incidence of lung cancer among uranium miners was done. Actually, an intuitive correlation of lung disease affecting miners was made as early as 1500, but it was not suspected to be radon-related carcinoma until the 1930s. No statistically-based studies of non-miners and radon have been made to date. Thus, the environmental risks of radon exposure to the average citizen cannot presently be established with confidence. Nonetheless, advisory standards for radon in air have been established, and standards for radon in water are under development.

Radon risk was not of universal concern to the public until 1984 when a worker at a nuclear generating facility in Pennsylvania triggered a personal radiation exposure alarm when he entered, not left, the plant. Investigation showed that his anomalous exposure was caused by excessive radon in his house. The story was featured by the *New York Times*, and the age of radon awareness began.

NATURAL RADIATION

Everyone on earth is subject to some degree of natural radiation (part of which comes from radon), commonly called "background." This background is mostly contributed from the rocks and surficial deposits or objects made from them. Cosmic rays also contribute radiation from outer space, and normal radioactive elements in the food chain add their component to complete this natural exposure. Further, since the nuclear age began, an additional contribution of radiation to the environment has been made from military hardware and reactor accidents.

Natural radiation is not considered to be a health hazard because the level of exposure is relatively low, and man has seemingly evolved successfully in harmony with it.

THE PHYSICS OF RADIATION

There are more than 100 chemical elements each consisting of several isotopes. The isotopes of any given element have the same number of protons, but different numbers of neutrons. The neutrons have mass, hence the isotopes come with different atomic weights. Some isotopes are unstable, and hence radioactive. This instability is called radioactive decay which lowers the atomic weight, forms a new isotope and a corresponding yield of nuclear energy. The form of this energy determines its radiation type and, in part, the destructive risk.

There are three unique types of radiation associated with radioactive decay (Table 1): *alpha, beta*, and *gamma*. Alpha radiation has mass, a relatively large radius, a positive (+2) charge, and is composed of two protons and two neutrons which move with a velocity of kilometers per second. Beta radiation is simply composed of high energy electrons, normally with a negative (-) charge. Beta is composed of nuclear electrons and has less mass than alpha, but these electrons have greater velocity. Gamma radiation is electromagnetic, has no mass, and travels at the speed of light. Considering the characters of mass and velocity of radiation, gamma has the greatest penetrating power and alpha the least. Alpha can, in fact, be arrested with a sheet of bond paper, but it is the most dangerous form of nuclear radiation for the damage it can do when colliding with living tissue. Gamma radiation is comparable to x-rays and is the least dangerous form of nuclear radiation in relatively low flux.

Table 1

NUCLEAR RADIATION

Type	***Charge***	***Composition***	***Velocity***	***Energy***
Alpha()	+	2 protons + 2 Neutrons (=nuclei of helium atom)	Thousands of km/sec	Maximum (< 12 Mev)
Beta()	- (+ in rare cases)	Nucleas electrons		Intermediate (< 4 mev)
Gamma()	(none)	Electromagnetic energy like X-rays, but of much shorter wave length (no mass)	C	Minimum (< 2 Mev)

C = velocity of light = 299,776 km/sec = 186,272 mil/sec

URANIUM AND HER DAUGHTERS

There are three isotopes of radon in nature, but only the isotope with an atomic weight of 222 (^{222}Rn) is abundant enough to be of environmental importance. ^{222}Rn is the product of the radioactive decay of radium (^{226}Ra) which is in the uranium (^{238}U) decay chain. For purposes of simplicity, only the ^{238}U decay chain is considered. In this arrangement uranium is the "parent" element and the lighter isotopes below are called the "daughter" products. Here we see a fundamental relationship: the abundance of radon in any given geologic domain is a function of uranium distribution. Radon ultimately comes from uranium dispersed in the rocks and surficial deposits around us. Thus, radon potential is controlled by the geology, specifically the distribution and geochemistry of uranium. Granite and metamorphic rocks are among the rocks of the earth's crust that can be especially endowed with uranium. New Hampshire is underlain by nearly equal amounts of these rocks, thus radon is of critical concern here.

Radioactive isotopes are unstable and decay at specific measurable variable rates. It is a mathematical convenience, therefore, to express these rates of decay in terms of "half-life," or the time it takes for one-half of a given amount to decay to the next "lower" isotope or a stable isotope (fig. 1 and fig. 2). Note that radon has a half-life of only 3.8 days, in contrast to uranium which has a 4.51 billion year half-life. Radon's relatively short half-life has important epidemiological consequences especially when considering the daughter products that follow from radon decay.

Element	Mass number	Atomic number	Half - Life	Radiation
U	238	92	4.5×10^{1} years	*a*
Th	234	90	24 days	*B*
Pa	234	91	6.7 hr, 1.2 min (2 isomers)	*B*
U	234	92	2.5×10^{5} years	*a*
Th	230	90	8×10^{4}	*a*
Ra	226	88	1,620 years	*a*
Ra	222	86	3.8 days	a
Po	218	84	3 min	99.97% a, 0.03% *B*
Pb	214	82	26.8 min.	B
or At	218	85	2 sec.	*a*
Bi	214	83	20 min.	99.6% B, 0.04% *a*
Po	214	84	1.6×10^{-4} sec.	a
or Ti	210	81	1.3 min.	*B*
Pb	210	82	22 years	B
Bi	210	83	5 days	*B*
Po	210	84	138 days	a
Pb	206	82		

				$8a + 6B$

Figure 1. The Uranium -238 Natural Radioactive Series
Figure 2.(not shown)
The uranium-238 decay series showing the half-lives of elements and their modes of decay.

There are a number of ways to express the measurement of radiation, but the Curie Standard (named for French physicist Marie Curie) has been adapted as a matter of convenience for radon. A curie is the amount of radiation emitted from one gram of ^{226}Ra. This is relatively a lot of radiation, and the use of the pico-Curie per liter (pCi/L) is the most convenient measure. One pCi is one trillionth of a curie (10^{-12}). Thus, the concentration of radon can be expressed in terms of either a liter of air or water.

RADON TRANSPORT

Health risk concerns about radon require separate approaches for radon in air, which is inhaled into the lungs, and radon in water, which is mostly ingested into the digestive tract. Though there is a danger of cell damage from the powerful alpha radiation energy produced from the decay of radon, a far greater risk comes from the radiation emitted by radon's daughters which can reside within the body because they are compatible with human biochemistry. Radon-rich water arrives with human biochemistry. Radon-rich water arrives with a considerable population of its daughter products because of the short half-life of the isotope. Radon levels in outdoor air, indoor air, air in fractured rocks and surficial deposits, surface water, and groundwater can be quite different (fig. 3).

Fig. 3(not shown) Radon Levels in Air and Water

GEOLOGY OF RADON

It has been observed that radon production is ultimately linked to the natural distribution of uranium in the earth's crust. All rocks contain measurable amounts of uranium varying according to their geochemical controls and genesis. Background amounts of uranium are less than 3 parts per million (ppm) in most rocks and surficial deposits. Uranium content in rocks can, however, vary greatly up to ore grade (>1,000 ppm). Surficial deposits are derived from the process of mechanical and chemical weathering of rocks, often with transport and redeposition by ice, water, or wind. Most of these deposits also contain less than 3 ppm uranium. Residual soils and closely redeposited weathering products of rocks, thus, tend to mimic the uranium content of the rocks that they came from if chemical weathering has not been profound. This is especially true of some glacial tills which are abundant in New Hampshire.

Some rocks frequently have an above-average uranium content, including specialized granite, light-colored volcanic rocks, carbonaceous shales, and metamorphic rock. We have observed that New Hampshire is underlain almost entirely be granitic and metamorphic rocks. Interestingly, many of the metamorphic rocks were deposited as light colored volcanics, such as rhyolite, and black carbonaceous sediments. Thus, many rocks of the state present a high potential for uranium. Fortunately, most of the granite in the state is of a type that is known to have a low to moderate uranium content (<5 ppm). One variety of red to pink granite in the White Mountains, Conway Granite, is among the most uranium-rich known in the world (averaging about 25 ppm). This particular rock, however contains abundant weathering-resistant accessory minerals, such as zircon, which effectively lock-up the uranium (and most of the radon) making the rocks less dangerous than they could be.

A unique type of granite, called "two-mica granite," and related pegmatite is abundant in the southeastern, central, and western parts of the state. This rock is characterized by moderate amounts of uranium (about 5 to 10 ppm), but it contains only minor amounts of resistate accessory minerals. Thus, the uranium is quite mobile (labile) in weathering processes in these rocks, and is capable of being dissolved and redeposited into local concentrations, sometimes exceeding ore-grade, creating sources of radon.

A unique type of uranium deposit that is found in peat has recently been discovered in New Hampshire as well as in other states. Some of these deposits can contain as much as 1 percent uranium. This uranium is young," however, fractionated away from its daughters. As such, it is not notably radioactive because of the long half-life of uranium, and it is not associated with significant radon. It can, however, present a risk as a toxic metal.

Faults, fractures, fissures, and especially the shatter zones which cut the rocks, can be important conduits for radon migration. Some of these features have been identified in New Hampshire where the structures are venting radon either from groundwater found along them or uranium deposits that have formed there. Glacial till that is comprised of material from uranium-rich rocks and transported by ice movement can also present a radon source over rocks not other wise enriched in uranium. Thus, in areas with faults, shatter zones, and glacial tills, there is not always a direct correlation between rocks and radon.

RADON RISK MAPS

As noted, the distribution of uranium in the bedrock is dependent on a combination of the genesis, geochemistry, and mineral content of a rock unit. Fractionation of uranium into surficial deposits is dependent on variables such as weathering processes, transport, and redesposition sedimentation of bedrock products. In order to assess radon potential, knowledge of the character and distribution of rock types and surficial deposits must be known. Such information is furnished by geologic maps of different types (fig. 4). These geologic maps can also be augmented by radioactivity maps that portray directly measured values made either on the ground or from the air (fig. 5). From these types of maps, derivative maps can then be created that show radon potential for estimating human risk. The ultimate map is obviously one complied from direct ground emanation of radon measured with special instruments that, quite literally, "sniff" radon. These maps compiled at scales fo 1:24,000 (1" equals about 0.4 mil) and larger have engineering importance and can be useful in deciding upon the suitability of land for development. Such maps, however, would be of limited use in forecasting radon levels in water wells drilled into the bedrock.

Fig. 4(not shown) Generalized Geologic Map of New Hampshire

Fig. 5(not shown) Aerial Radiometric Map of New Hampshire

RADON IN THE ENVIRONMENT

Outdoor Air. Radon in outdoor air poses no risk to human health. The range in concentration varies from 0.1 pCi/L to 30 pCi/L, averaging about 0.2 pCi/L. Higher, but not dangerous, concentrations are possible during passive weather conditions along the floors of sharp topographic depressions that signal faults and shatter zones. No deep mines are operated in New Hampshire, and quarries operated for stone and aggregate production are probably sufficiently ventilated by nature to present no radon risk.

Surficial Deposits. Air (soil air) in water-unsaturated surficial deposits including glacial sediments has much more variable concentrations and higher levels of radon than free air. These levels vary from about 100 pCi/L to more than 100,000 pCi/L, but probably average between 200 and 2,000 pCi/L near the surface. The radon in these surficial deposits is mainly attributable to the decay of radium. Soil gas radon can come from groundwater evaporating or "pumping" within the surficial deposits, especially during periods when the water table is rising and falling. Once mobile in the soil, the radon is free to respond to the controls of the *diffusion* gradient (migration from a higher to a lower concentration) and *flow* (pressure) gradient.

Surface Water. Radon in surface water is free to rapidly enter the atmosphere, and thus seldom exceeds levels of about 100 pCi/L. Certainly, public surface water supplies do not pose a radon risk. Moreover, these waters are required to be tested for radioactivity. Some springs in New Hampshire, especially in the western part of the state, are known from ground radiation measurements to carry appreciable amounts of radon. Testing them for radon is recommended, especially where spring waters are emanating from known faults, fissures in two-mica granite, and either rocks or surficial deposits, especially within the White Mountains.

Groundwater. Groundwater is obtained in New Hampshire from surficial deposits (dug wells and screened wells) and from bedrock sources (drilled wells). The water in surficial deposits is contained in pore space, and the water in rock-drilled wells is contained principally in fractures (secondary porosity).

The crystalline rocks of the state do not have appreciable primary porosity. The radon levels in New Hampshire groundwater vary as much as six orders of magnitude ranging from about 100 pCi/L to as much as 4 million pCi/L! The groundwaters of primary porosity in surficial deposits carry much lower radon levels than those of secondary porosity in bedrock. The radon level range of groundwater of primary porosity is not established with any confidence, but is probably less than 40,000 pCi/L in most wells.

There is a general consensus among specialists working in radon that 10,000 to 20,000 pCi/L of radon in groundwater is cause for concern and 100,000 pCi/L requires remedial action. Levels of radon approaching 100,000 pCi/L in water supplies are capable of being the principal contributors to excessive radon levels in the built environment simply by degassing during water use.

Research into the geology of radon has not progressed to the point where the radon potential of a proposed well in bedrock can be predicted. We know that parameters such as (1) well depth, (2) depth of water production, (3) water yield, (4) pumping rate (stress), and (5) proximity of other wells play important roles. Studies in New Hampshire have not, to date, produced any consistent pattern. It appears, in fact, that drilled wells each have individual personalities. The only consistent relationship appears to be related to rock type. Thus, well planning, including a concern for radon, begins with the interpretation of a geologic map. The evolving technology of drilling into bedrock to exploit the groundwater resource opens questions about artificially accelerating the mobility of radon by pumping stress. It is reasonable to believe that stressing an aquifer increases groundwater mobility rates far beyond those predicted by nature. Such accelerated rates could result in "sweeping" a much larger volume of rocks for its groundwater and enhancing both radon concentration and mobility.

A corollary to this observation raises another interesting question. How do radon levels of well water immediately after drilling compare to radon levels after sustained use? Some rock wells in New Hampshire have, indeed, shown a steady build-up of radon with service, but others have shown fluctuating radon levels with time and season. Further, the dynamics of bedrock aquifer recharge also has much to do with radon level.

It becomes obvious that no two aquifers are alike and, therefore, no consistent set of variables govern the potential for radon in the groundwater.

Habitat and Workplace. Ancestral man unwittingly placed himself at risk with radon when he took up residence in certain caves and used water from radon-enriched springs. The course of human history has been, therefore, one of coexistence with the isotope, but obviously with ever-increasing exposure. As technology advanced, man learned to enjoy the comforts of enclosed architecture which eventually brought conveniences such as central heating. In short, the evolution of architecture and equipment brought about the opportunity for radon to concentrate in the built environment, especially in climates marked by a distinct winter season.

Cold weather results in reducing ventilation and creating a pressure differential between the colder atmosphere and the heated structure. Such a differential results in the structure acting as "vacuum cleaner" for radon-slaked soil gas if basement floors and foundations are not sealed. If there is an important amount of radon in the water supply, aeration by equipment such as showers and washing machines add this radon to that already there. Air conditioning of structures diminishes the ventilation, but the pressure differential is reversed. Structures without air conditioning are ventilated to the atmosphere and reduce the radon risk in the warmer months.

Meaningful statistics for radon levels in New Hampshire structures exist only for indoor air in homes. A study completed by the N.H. Division of Public Health Services on a random selection of 1,810 homes between 1988 and 1990 found that the average was 4.8 pCi/L and that 27.8 percent of the homes recorded levels in excess of 4 pCi/L. One home was measured at 479 pCi/L.

Interim hazard levels of 4 pCi/L in air and 40,000 pCi/L in water have been used in advisory context. As a first approximation, 40,000 pCi/L in the water supply of a home results in 4 pCi/L in the household air. Almost 7,000 public and private water supplies in New Hampshire have been tested for radon levels (Table 2). More than 16 percent of these supplies exceed 10,000 pCi/L which is probably a level that can make a measurable, but not dangerous, contribution to the radon within structures. About 18 percent of New Hampshire homes and some commercial buildings are dependent upon private unregulated water supplies obtained from wells drilled into bedrock. Radon testing to date in this class of water supply indicates that 5 to 10 percent of the well waters exceed 40,000 pCi/L. It has been noted that such waters can make a potentially unhealthful contribution of radon to the indoor air. The amount of this contribution, however, depends on variables, especially the volume of air and the volume of water used during a specified period of time.

Table 2.
Radon Analysis in New Hampshire Water Supplies (data from DES laboratories for a sample group from 1/1/84 through 12/31/92).

Radon - 222 (pCi/L.)	Community	Non-community	Private
0 - 300	539 18.9%	68 9.3%	219 6.4%
301 - 10,000	1856 65.1%	549 75.0	2360 69.4
10,001 - 40,000	407 14.3	85 11.6	648 19.1
Greater than 40,000	48 1.6	30 4.1	172 5.1
Totals	**2850**	**732**	**3399**

	pCi/L	**Total**	
Grand Total 6981	0 - 300	826	11.8%
	301 - 10,000	4765	68.3
	10,001 - 40,000	1140	16.3
	> 40,000	250	3.6

RECOMMENDED HUMAN RESPONSE

Once "excessive" levels of radon are delivered "free of charge" by geology, mitigation becomes a problem for engineers and health specialists. In cases where groundwater is not the major contributor of radon into a structure, a combination of ventilation and sealing is indicated to prevent radon build-up and recharge. The elimination of excessive radon in water is also possible through the use of engineered devices that aerate the radon into the atmosphere. The daughter products of radon that the water also carries can be stripped and captured by adsorption or chemical exchange-processing systems such as activated charcoal filters. *The use of such systems, however, requires a commitment to the safe disposal of cartridges or liquids that become dangerously radioactive*.

Pioneering work has been done by the Environmental Research Group at the University of New Hampshire in safely reducing the levels of radon and its decay products from water supplies. The U.S. Environmental Protection Agency maintains a register of commercial specialists approved to do radon mitigation in indoor air and water. The use of only approved practitioners is strongly advised.

It is recommended that all residents of New Hampshire test their dwellings for indoor air radon levels. Also, homes and commercial buildings supplied from wells drilled into bedrock should test their water supplies. Ideally, water in newly drilled wells should be tested both before sustained use and then several months to a year later. If the radon level has increased significantly on the second test, yearly periodic tests should be done until the radon level stabilizes. Water tests can be done by either EPA-certified commercial testing laboratories or by the state analytical chemistry laboratory operated by DES in Concord. New Hampshire residents are showing an increasing commitment not only informing themselves about radon risk, but also assuring themselves that radon levels in their indoor air and water supplies are at "safe" levels.

FOR FURTHER INFORMATION

Questions on radon mitigation and health risk should be directed to Bureau of Radiological Health Services, Health and Welfare Building, 29 Hazen Drive, Concord, NH 03301, (603) 271-4674 or 1-800-852-3345 x-4674.

SUGGESTIONS FOR ADDITIONAL READING

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